

CLAIMS

1 1. A method for rendering a volume of voxel data with shading and opacity, wherein
2 each voxel comprises a value representative of a parameter at a location within the
3 volume and each voxel has an initial value of opacity, the method comprising the steps
4 of:

5 calculating a revised value of opacity for each of the voxels in the volume, the
6 revised value of opacity of a voxel being dependent upon its initial value of opacity and
7 the revised value of opacity of voxels proximate thereto; and

8 calculating an opacity gradient for each of the voxels in the volume using the
9 calculated revised values of opacity for all voxels.

1 2. The volume rendering method of claim 1 wherein the step of calculating a revised
2 value of opacity further comprises the step of:

3 creating a cell of voxels surrounding each voxel in the volume, wherein all voxels
4 in each cell are arranged into groups so that each voxel in each group of voxels within
5 each cell are positioned one behind the other in a line parallel to the primary direction of
6 light.

1 3. The volume rendering method of claim 2 wherein the step of calculating a revised
2 value of opacity further comprises the steps of:

3 setting the revised value of opacity of the voxel closest to the source of light in
4 each group of voxels in each cell equal to its initial value of opacity; and

5 setting the revised value of opacity of all other voxels in each group of voxels in
6 each cell equal to the revised value of opacity of an adjacent voxel in the same group of
7 voxels that is closer to the source of light if the revised value of opacity of the closer
8 voxel is equal to or greater than the initial value of opacity of the adjacent other voxel,
9 and setting the revised value of opacity of the adjacent other voxel equal to its initial

10 value of opacity if the revised value of opacity of the closer voxel is less than the initial
11 value of opacity of the adjacent other voxel.

1 4. The volume rendering method of claim 3 wherein the step of calculating an
2 opacity gradient for each of the voxels in the volume using the calculated revised values
3 of opacity for all voxels further comprises the steps of:

4 combining the revised values of opacity for the voxels in each cell to derive three
5 orthogonal opacity gradient components for the voxel in the center of each cell; and

6 combining the three orthogonal opacity gradient components for the voxel in the
7 center of each cell to derive an opacity gradient that is normal to an isosurface passing
8 through the voxel in the center of each cell.

1 5. The volume rendering method of claim 1 wherein the step of calculating an
2 opacity gradient for each of the voxels in the volume using the calculated revised values
3 of opacity for all voxels further comprises the steps of:

4 combining the revised values of opacity for the voxels in each cell to derive three
5 orthogonal opacity gradient components for the voxel in the center of each cell; and

6 combining the three orthogonal opacity gradient components for the voxel in the
7 center of each cell to derive an opacity gradient that is normal to an isosurface passing
8 through the voxel in the center of each cell.

1 6. The volume rendering method of claim 4 further comprising the steps of:
2 calculating shading for the volume using the opacity gradient; and
3 displaying the rendered volume on the display device.

1 7. The volume rendering method of claim 1 further comprising the steps of:
2 calculating shading for the volume using the opacity gradient; and
3 displaying the rendered volume on the display device.

1 8. A method for rendering a volume of voxel data with shading and opacity
2 dependent upon the direction of a source of light specified to be illuminating the volume
3 for rendering, wherein each voxel comprises a value representative of a parameter at a
4 location within the volume and each voxel has an initial value of opacity, the method
5 comprising the steps of:

6 (1) calculating a revised value of opacity for a first voxel in the volume by creating a
7 cell of voxels surrounding the first voxel, wherein all voxels in the cell are arranged into
8 groups so that each voxel in each group of voxels within the cell are positioned one
9 behind the other in a line parallel to the primary direction of light, the revised opacity
10 calculation step further comprising the steps of:

11 (a) setting the revised value of opacity of the voxel closest to the source of
12 light in each group of voxels in the cell equal to its initial value of
13 opacity; and
14 (b) setting the revised value of opacity of other voxels in the groups of voxels
15 in the cell equal to the revised value of opacity of an adjacent voxel in the
16 same group of voxels that is closer to the source of light if the revised
17 value of opacity of the closer voxel is equal to or greater than the initial
18 value of opacity of the other voxel, and setting the revised value of
19 opacity of the other voxel equal to the initial value of opacity of the other
20 voxel if the revised value of opacity of the closer voxel is less than the
21 initial value of opacity of the other voxel;

22 (2) repeating the revised opacity calculations step for all other voxels in the volume
23 other than the first voxel; and
24 (3) calculating a gradient of opacity for each of the voxels in the volume using the
25 calculated revised values of opacity for all voxels.

1 9. The volume rendering method of claim 8 wherein the step of calculating an
2 opacity gradient for each of the voxels in the volume using the calculated revised values
3 of opacity for all voxels further comprises the steps of:

4 combining the revised values of opacity for the voxels in each cell to derive three
5 orthogonal opacity gradient components for the voxel in the center of the last mentioned
6 cell; and

7 combining the three orthogonal opacity gradient components for the voxel in the
8 center of each cell to derive an opacity gradient that is normal to an isosurface passing
9 through the voxel in the center of the last mentioned cell.

1 10. The volume rendering method of claim 8 further comprising the steps of:
2 calculating shading for the volume using the opacity gradient; and
3 displaying the rendered volume on the display device.

1 11. The volume rendering method of claim 9 further comprising the steps of:
2 calculating shading for the volume using the opacity gradient; and
3 displaying the rendered volume on the display device.

1 12. A method for rendering a volume of voxel data with shading and opacity
2 dependent upon the direction of a source of light specified to be illuminating the volume
3 for rendering, wherein each voxel comprises a value representative of a parameter at a
4 location within the volume and each voxel has an initial value of opacity, the method
5 comprising the steps of:

6 (1) calculating a revised value of opacity for a first voxel in the volume by
7 creating a cell of voxels surrounding the first voxel, wherein all voxels in the cell are
8 arranged into groups so that each voxel in each group of voxels within the cell are
9 positioned one behind the other in a line parallel to the primary direction of light, the
10 revised opacity calculation step further comprising the steps of:

11 (a) setting the revised value of opacity of the voxel closest to the source
12 of light in each group of voxels in the cell equal to its initial value of opacity;

13 (b) setting the revised value of opacity of other voxels in the groups of
14 voxels in the cell equal to the revised value of opacity of an adjacent voxel in the

15 same group of voxels that is closer to the source of light if the revised value of
16 opacity of the closer voxel is equal to or greater than the initial value of opacity of
17 the other voxel, and setting the revised value of opacity of the other voxel equal to
18 the initial value of opacity of the other voxel if the revised value of opacity of the
19 closer voxel is less than the initial value of opacity of the other voxel;

20 (2) repeating the revised opacity calculations step for all other voxels in the
21 volume other than the first voxel;

22 (3) calculating three orthogonal opacity gradient components for the first voxel,
23 one of the orthogonal opacity gradient components being parallel to the primary direction
24 of light, the opacity gradient calculation step further comprising the steps of:

25 (a) combining the revised values of opacity for the voxels in the cell to
26 derive the three orthogonal opacity gradient components for the first voxel; and

27 (b) combining the three orthogonal opacity gradient components for the
28 first voxel to derive an opacity gradient that is normal to an isosurface passing
29 through the first voxel;

30 (c) repeating the opacity gradient calculation step for all other voxels in
31 the volume other than the first voxel.

1 13. The volume rendering method of claim 12 further comprising the steps of:
2 calculating shading for the volume using the opacity gradient; and
3 displaying the rendered volume on the display device.

1 14. Apparatus for rendering a volume of voxel data with shading and opacity,
2 wherein each voxel comprises a value representative of a parameter at a location within
3 the volume and each voxel has an initial value of opacity, the rendering apparatus
4 comprising:

5 means for calculating a revised value of opacity for each of the voxels in the
6 volume, the revised value of opacity of a voxel being dependent upon its initial value of
7 opacity and the revised value of opacity of voxels proximate thereto; and

8 means for calculating an opacity gradient for each of the voxels in the volume
9 using the calculated revised values of opacity for all voxels.

1 15. The volume rendering apparatus of claim 14 wherein the means for calculating a
2 revised value of opacity further comprises:

3 means for creating a cell of voxels surrounding each voxel in the volume, wherein
4 all voxels in each cell are arranged into groups so that each voxel in each group of voxels
5 within each cell are positioned one behind the other in a line parallel to the primary
6 direction of light.

1 16. The volume rendering apparatus of claim 15 wherein the means for calculating a
2 revised value of opacity further comprises:

3 means for setting the revised value of opacity of the voxel closest to the source of
4 light in each group of voxels in each cell equal to its initial value of opacity; and

5 means for setting the revised value of opacity of all other voxels in each group of
6 voxels in each cell equal to the revised value of opacity of an adjacent voxel in the same
7 group of voxels that is closer to the source of light if the revised value of opacity of the
8 closer voxel is equal to or greater than the initial value of opacity of the adjacent other
9 voxel, and setting the revised value of opacity of the adjacent other voxel equal to its
10 initial value of opacity if the revised value of opacity of the closer voxel is less than the
11 initial value of opacity of the adjacent other voxel.

1 17. The volume rendering apparatus of claim 16 wherein the means for calculating an
2 opacity gradient for each of the voxels in the volume using the calculated revised values
3 of opacity for all voxels further comprises:

4 means for combining the revised values of opacity for the voxels in each cell to
5 derive three orthogonal opacity gradient components for the voxel in the center of each
6 cell; and

7 means for combining the three orthogonal opacity gradient components for the
8 voxel in the center of each cell to derive an opacity gradient that is normal to an
9 isosurface passing through the voxel in the center of each cell.

1 18. The volume rendering apparatus of claim 14 wherein the means for calculating an
2 opacity gradient for each of the voxels in the volume using the calculated revised values
3 of opacity for all voxels further comprises:

4 means for combining the revised values of opacity for the voxels in each cell to
5 derive three orthogonal opacity gradient components for the voxel in the center of each
6 cell; and

7 means for combining the three orthogonal opacity gradient components for the
8 voxel in the center of each cell to derive an opacity gradient that is normal to an
9 isosurface passing through the voxel in the center of each cell.

1 19. The volume rendering apparatus of claim 17 further comprising:

2 means for calculating shading for the volume using the opacity gradient; and
3 means for displaying the rendered volume on a display device.

1 20. The volume rendering apparatus of claim 14 further comprising:

2 means for calculating shading for the volume using the opacity gradient; and
3 means for displaying the rendered volume on a display device.

1 21. Apparatus for rendering a volume of voxel data with shading and opacity
2 dependent upon the direction of a source of light specified to be illuminating the volume
3 for rendering, wherein each voxel comprises a value representative of a parameter at a
4 location within the volume and each voxel has an initial value of opacity, the apparatus
5 comprising:

6 (1) means for calculating a revised value of opacity for a first voxel in the volume
7 by creating a cell of voxels surrounding the first voxel, wherein all voxels in the cell are

8 arranged into groups so that each voxel in each group of voxels within the cell are
9 positioned one behind the other in a line parallel to the primary direction of light, the
10 revised opacity calculation means further comprising:

11 (a) means for setting the revised value of opacity of the voxel closest to
12 the source of light in each group of voxels in the cell equal to its initial value of
13 opacity; and

14 (b) means for setting the revised value of opacity of other voxels in the
15 groups of voxels in the cell equal to the revised value of opacity of an adjacent
16 voxel in the same group of voxels that is closer to the source of light if the revised
17 value of opacity of the closer voxel is equal to or greater than the initial value of
18 opacity of the other voxel, and setting the revised value of opacity of the other
19 voxel equal to the initial value of opacity of the other voxel if the revised value of
20 opacity of the closer voxel is less than the initial value of opacity of the other
21 voxel;

22 (2) means for repeating the revised opacity calculations for all other voxels in the
23 volume other than the first voxel; and

24 (3) means for calculating a gradient of opacity for each of the voxels in the
25 volume using the calculated revised values of opacity for all voxels.

1 22. The volume rendering apparatus of claim 21 wherein the means for calculating an
2 opacity gradient for each of the voxels in the volume using the calculated revised values
3 of opacity for all voxels further comprises:

4 means for combining the revised values of opacity for the voxels in each cell to
5 derive three orthogonal opacity gradient components for the voxel in the center of the last
6 mentioned cell; and

7 means for combining the three orthogonal opacity gradient components for the
8 voxel in the center of each cell to derive an opacity gradient that is normal to an
9 isosurface passing through the voxel in the center of the last mentioned cell.

- 1 23. The volume rendering apparatus of claim 21 further comprising:
2 means for calculating shading for the volume using the opacity gradient; and
3 means for displaying the rendered volume on the display device.
- 1 24. The volume rendering apparatus of claim 22 further comprising:
2 means for calculating shading for the volume using the opacity gradient; and
3 means for displaying the rendered volume on the display device.
- 1 25. Apparatus for rendering a volume of voxel data with shading and opacity
2 dependent upon the direction of a source of light specified to be illuminating the volume
3 for rendering, wherein each voxel comprises a value representative of a parameter at a
4 location within the volume and each voxel has an initial value of opacity, the apparatus
5 comprising:
6 (1) means for calculating a revised value of opacity for a first voxel in the volume
7 by creating a cell of voxels surrounding the first voxel, wherein all voxels in the cell are
8 arranged into groups so that each voxel in each group of voxels within the cell are
9 positioned one behind the other in a line parallel to the primary direction of light, the
10 revised opacity calculation means further comprising:
11 (a) means for setting the revised value of opacity of the voxel closest to
12 the source of light in each group of voxels in the cell equal to its initial value of
13 opacity;
14 (b) means for setting the revised value of opacity of other voxels in the
15 groups of voxels in the cell equal to the revised value of opacity of an adjacent
16 voxel in the same group of voxels that is closer to the source of light if the revised
17 value of opacity of the closer voxel is equal to or greater than the initial value of
18 opacity of the other voxel, and setting the revised value of opacity of the other
19 voxel equal to the initial value of opacity of the other voxel if the revised value of
20 opacity of the closer voxel is less than the initial value of opacity of the other
21 voxel;

22 (2) means for repeating the revised opacity calculations for all other voxels in the
23 volume other than the first voxel;

24 (3) means for calculating three orthogonal opacity gradient components for the
25 first voxel, and one of the orthogonal opacity gradient components is parallel to the
26 primary direction of light, the opacity gradient calculation means further comprising :

27 (a) means for combining the revised values of opacity for the voxels in
28 the cell to derive the three orthogonal opacity gradient components for the first
29 voxel;

30 (b) means for combining the three orthogonal opacity gradient
31 components for the first voxel to derive an opacity gradient that is normal to an
32 isosurface passing through the first voxel; and

33 (c) means for repeating the opacity gradient calculations for all other
34 voxels in the volume other than the first voxel; and

35 (4) means for calculating shading for the volume using the opacity gradient.

- 1 26. The volume rendering apparatus of claim 12 further comprising:
2 means for calculating shading for the volume using the opacity gradient; and
3 means for displaying the rendered volume on the display device.
- 1 27. A computer readable medium containing executable instructions for rendering on
2 a display device a volume of voxel data with shading and opacity dependent upon the
3 direction of a source of light specified to be illuminating the volume for rendering,
4 wherein each voxel comprises a value representative of a parameter at a location within
5 the volume and each voxel has an initial value of opacity, the executable program
6 instructions comprising program instructions for:
7 (1) calculating a revised value of opacity for a first voxel in the volume by
8 creating a cell of voxels surrounding the first voxel, wherein all voxels in the cell are
9 arranged into groups so that each voxel in each group of voxels within the cell are

10 positioned one behind the other in a line parallel to the primary direction of light, the
11 revised opacity calculation means further comprising:
12 (a) setting the revised value of opacity of the voxel closest to the source
13 of light in each group of voxels in the cell equal to its initial value of opacity; and
14 (b) setting the revised value of opacity of other voxels in the groups of
15 voxels in the cell equal to the revised value of opacity of an adjacent voxel in the
16 same group of voxels that is closer to the source of light if the revised value of
17 opacity of the closer voxel is equal to or greater than the initial value of opacity of
18 the other voxel, and setting the revised value of opacity of the other voxel equal to
19 the initial value of opacity of the other voxel if the revised value of opacity of the
20 closer voxel is less than the initial value of opacity of the other voxel;
21 (2) repeating the revised opacity calculations for all other voxels in the volume
22 other than the first voxel;
23 (3) calculating a gradient of opacity for each of the voxels in the volume using
24 the calculated revised values of opacity for all voxels; and
25 (4) calculating shading for the volume using the opacity gradient.

1 28. A computer readable medium containing executable instructions for rendering on
2 a display device a volume of voxel data with shading and opacity, wherein each voxel
3 comprises a value representative of a parameter at a location within the volume and each
4 voxel has an initial value of opacity, the method comprising the steps of:
5 calculating a revised value of opacity for each of the voxels in the volume, the
6 revised value of opacity of a voxel being dependent upon its initial value of opacity and
7 the revised value of opacity of voxels proximate thereto;
8 calculating an opacity gradient for each of the voxels in the volume using the
9 calculated revised values of opacity for all voxels; and
10 calculating shading for the volume using the opacity gradient.
